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PREDICTING RETENTION EFFECTS OF A RIPARIAN ZONE IN AN AGRICULTURAL LANDSCAPE: IMPLICATION FOR EUTROPHICATION CONTROL OF THE TISZA RIVER, SERBIA

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Abstract: We explored the long-term influence of land use in the riparian zone on the water quality of the Tisza River, as a model of a non-wadeable lowland river located in a temperate, predominantly agricultural landscape. The analysis was based on a comparison of water quality variables between three river sites having contrasting, but constant land use patterns (in 500 m upstream radius) during the study period (2006-2019). While the first river site was characterized primarily by forests, the second and the third were dominated by urban and agricultural areas respectively. The variables which showed a significant difference between the pairs of sampling sites were oxygen saturation, nitrite nitrogen, total nitrogen, and orthophosphates. In contrast to urban and agricultural land, riparian forests showed a positive long-term influence on the river water quality. Natural and seminatural forests and shrubs had a favorable long-term influence on nutrient concentrations and oxygen regime of the Tisza River. However, the retention effects of orthophosphates and nitrite/nitrate content here were relatively low, demonstrating the limited performance of riparian buffers as a main or only management option in the Pannonian landscape, as the agricultural hotspot of Central and Eastern Europe. In conclusion, the riparian buffer assessment design applied in this study may be successfully used in pre-restoration monitoring, prior to the construction of buffer strips.

Keywords: buffer zone, land cover, riparian, riparian buffer, water quality

1. INTRODUCTION

Eutrophication of freshwater ecosystems is a natural process, which implies an increase in organic matter production and relatively slow successional changes from aquatic to terrestrial habitats. Various human pressures may accelerate this process, including point and non-point nutrient sources, primarily nitrogen and phosphorus. This cultural eutrophication may further lead to a significant decrease in water quality, as well as the loss of biodiversity and ecosystem services (Dodds et al., 2009; Barbosa et al., 2020; Miletić et al., 2022). According to Moal et al., (2019), addressing this burning environmental problem could be challenging, due to the long-term impacts multiple anthropogenic activities have on water quality.

The relationship between land use and water eutrophication parameters has been well-described for different aquatic ecosystems, spatial scales, and climate zones (Gu et al., 2019; Yadav et al., 2019; Wang et al., 2020; Brumberg et al., 2021). Previous studies have shown that up to one-half of variation in water quality can be explained by land use patterns, either at a local or watershed scales (Vrebos et al., 2017; Liang et al., 2020; Song et al., 2020). While agricultural land is considered a non-point source of total nitrogen and orthophosphates, urban areas represent a complex of non-point and point sources of total phosphorus and ammonia nitrogen (Monteagudo et al., 2012; Yadav et al., 2019; Song et al., 2020).

Riparian buffers are a widely used management option for the protection and improvement of water quality in rivers (Haag & Kaupenjohann, 2001; Aguiar et al., 2015; Su et al., 2015; Grudzinski et al., 2020). As transition areas between the water body and the riparian zone, they may slow down erosion, and improve water quality by trapping nutrients (Cole et al., 2020). However, the effectiveness of the river buffer zone depends on many factors, such as the buffer width and length, vegetation cover type, as well its cost-effectiveness (Aguiar et al., 2015; Tiwari et al., 2016; Brumberg et al., 2021). Buffer width can be a key factor preventing nutrients (especially nitrogen and phosphorus) from reaching the aquatic ecosystem from surrounding areas (Aguiar et al., 2015). Brumberg et al. (2021) have shown that in the case of tropical rivers, the riparian buffer length had more influence on water quality than its width. In general, buffer zones composed of woody vegetation in agricultural areas were found to be more effective in nutrient removal, than less complex vegetation covers of the same width (Aguiar et al., 2015). However, when agriculture is the predominant land use type in the entire watershed, it is difficult to explore potential influences of narrow riparian buffer zones and water quality (Yadav et al., 2019).

Most of the studies dealing with the land use/water quality relationship in predominantly agricultural landscapes include datasets collected over relatively short time periods (i.e. several years) (Kellner et al., 2018), and/or on different rivers within a single (sub)-watershed (e.g. Nava-López et al., 2016; Liang et al., 2020). At the same time, there are a few case studies trying to explore and prove the long-term effect of riparian land cover restoration/changes on water quality of a single water body (Su et al., 2015; Feld et al., 2018). In this sense, Feld et al., (2018) have stressed the urgent need for long-term assessment of riparian buffer effects based on the comparison of environmental conditions before and after the buffer construction (Underwood, 1991), but reported this kind of study as extremely rare. Therefore, we hypothesized that a potential substitute to the BACI approach in the buffer pre-construction phase could be a long-term comparison of water quality at two river sites, having different (contrasting) land use patterns in the buffer zone (natural and artificial), which remain consistent during the study period. This study approach might also provide valuable information regarding the buffer effectiveness, prior to any management action on a particular river. As an added benefit, data sets required for such study designs are usually available from regular monitoring networks (Read et al., 2017).

Consequently, this study aimed to explore the long-term influence of contrasting land use types in the riparian zone on the water quality of the Tisza River, as a model of a non-wadeable lowland river located in a temperate, predominantly agricultural landscape. To this end, the following tasks were set: i) to select national water quality (WQ) monitoring sampling sites appropriate for the analysis (sites should have a consistent land use pattern during the sampling period within the 500 m upstream radius; sites should differ from each other by the dominant riparian land cover class); ii) to reveal WQ variables which are significantly different between each pair of the selected sampling sites (e.g. site dominated with natural land cover against a site dominated with artificial land use); iii) evaluate the potential long-term retention effects of a buffer zone with predominantly natural land cover.

2. MATERIALS AND METHODS

2.1. Study area

Tisza River is a major Danube tributary, with a 157,000 km^2 catchment area and a total length of 966 km. This study included the lowland section of the Tisza River in Serbia, with a mean water slope (4.5 cm/km) and an average discharge of 1970 m^3/s (Pavić, 2006; ICPDR, 2008 Pavić et al., 2009). Hydromorphological alterations reduced the length of the entire lower (Serbian) section of the Tisza River by about 30% (Pavić, 2006; ICPDR, 2008 Pavić et al., 2009). In general, this catchment is considered one of the most productive agricultural areas of the Carpathian Basin (Nagy et al., 2018).

2.2. Data sets and analysis

2.2.1 Site selection

To determine WQ sampling sites appropriate for the analysis, the network of sampling stations of the Environmental Protection Agency of the Republic of Serbia (SEPA) (http://www.sepa.gov.rs/) in the Tisza watershed was considered. For each candidate sampling point, the land use pattern was estimated at different spatial scales (Vari et al., 2022) i) within the 500 m radius upstream from the sampling sites (Shi et al., 2017; Gu et al., 2019), and ii) within the 20 km radius around the sampling sites (Yadav et al., 2019; Xu et al., 2019). The analysis was carried out in QGIS using the CORINE land-cover databases for Europe for 2006, 2012, and 2018 (CLC, 2006; CLC, 2012; CLC, 2018; EEA, 2021). For each radius, the percentage of the following land cover types were calculated: artificial urban surfaces, agricultural areas, and forests with semi-natural areas (including only forests and transitional woodland shrubs).

Sampling sites along the river were selected based on several criteria. Each sampling site was required to have a consistent distribution of land cover types within the 500 m upstream radius during the sampling period (2006-2014). The sampling sites were required to differ between each other by the dominant land cover class (e.g. artificial urban surfaces/agricultural areas/forests), within the 500 m upstream radius. Also, all sampling sites needed to have equal proportions of agricultural areas within the 20 km radius, to exclude any potential influences on the results at this spatial scale. The 20 km scale was reported in previous studies as the maximal relevant scale in the prediction of river trophic attributes by surrounding agricultural land cover (Yadav et al., 2019; Xu et al., 2019). According to previous studies (Feld et al., 2011, 2018; Song et al., 2020; Brumberg et al., 2021), the considered buffer parameters showed significant retention effect in rivers surrounded by arable land. Therefore, this site selection model allowed us to explore the influence of dominant land cover types within the local riparian scale (500 m upstream radius) on water quality in a predominantly agricultural watershed.

2.2.2. Data collection

For each selected sampling site, water quality (WQ) variables were extracted from the National monitoring database provided by SEPA. These variables included: dissolved oxygen [mg/l], oxygen saturation [%], pH, electroconductivity [µS/cm], nitrite nitrogen [mg/l], nitrate nitrogen [mg/l], organic nitrogen [mg/l], total nitrogen (TN) [mg/l], orthophosphates [mg/l], total phosphorus (TP) [mg/l], chloride Cl^- [mg/l], cadmium Cd [µg/l], chemical oxygen demand (COD) [mg/l], and biological oxygen demand (BOD) [mg/l]. Water quality parameters were measured monthly, from January 2006 to December 2019. Detailed sampling methods are provided in the Supplementary Material 1.

2.2.3. Data Analysis

The next step was to select the WQ variables which are significantly different between each pair of the sampling sites (e.g. site dominated by natural forests against a site dominated by urban areas). Prior to analysis, all variables were tested for normality using the Shapiro-Wilks test. Also, the non-parametric Friedman test was used to detect the interannual variability of each environmental variable at the sampling site dominated by natural land cover. This analysis was performed in SPSS 19. Only the sampling years with non-significant differences between each other were considered for further analysis. Consequently, the differences were tested between each pair of sampling sites for each environmental variable, for an 11–14-year sampling period.

The significant difference between the sampling site with natural, against the site with artificial land use indicated the role of the anthropogenic land cover for a particular physico-chemical variable (Valkama et al., 2019). Since the sampling sites are located along the same watercourse, the dependent sample t-test ($p < 0.05$) was performed, using STATISTICA 14 software (StatSoft, 2021). This allowed taking into account the influence of directional flow on water quality, as an essential unique river ecosystem characteristic (Vari et al., 2022). For variables with a non-normal distribution (electroconductivity, nitrate nitrogen, pH, orthophosphates), the Wilcoxon matched pairs test ($p < 0.05$) was carried out, as the non-parametric equivalent method. The Whisker plots with the mean and range values are shown only for WQ variables which show statistically significant differences between the sampling sites.

Finally, the potential retention effect of the natural riparian buffer zone (E) was evaluated. For each sampling site with artificial land use, which showed a significant WQ difference, compared to the site with natural land cover, the E value (Valkama et al., 2019) was calculated as:

$$E = N/A$$

where N is an average value of the particular environmental variable during the study period at the site with natural land use; and A represents the average value of the particular environmental variable within the site with artificial land use during the study period.

3. RESULTS

3.1 Land use pattern and sampling site selection

Following the set criteria, a total of three sampling sites along the Tisza River were selected for analysis (Figure 1): SS1 - upstream from the Martonoš village; SS2 - at the downstream edge of Novi Bečej town; and SS3 - on the upstream border of Titel town.

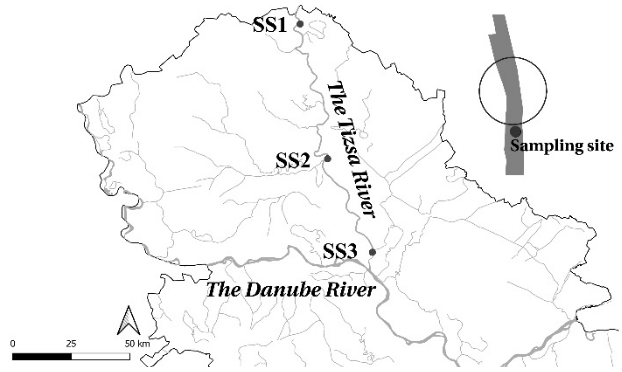

Figure 1. Geographical location of sampling sites and positioning of the 500 m upstream buffer.

Identical and consistent land use patterns were observed within the 20 km radius from all sampling sites during the entire study period (Figure 2). Agricultural areas were the dominant land cover type, while the proportion of artificial surfaces, forests and semi-natural areas, wetlands, and water bodies together accounted for up to 20%. On the other hand, land use pattern in the 500 m upstream radius differed between the sampling sites but remained relatively constant within each sampling site during the study period (Figure 3).

While SS1 was characterized primarily by natural and seminatural forests and woodland shrubs, SS2 was dominated by urban areas. The land use mosaic at SS3 mainly included agricultural areas, with a small proportion of urban areas, forests, and transitional woodland shrubs.

3.2. Significant water quality variables and retention effect of the natural riparian buffer

The Friedman test was used to detect the interannual variability of each environmental variable at the sampling site dominated by natural land cover (SS1). Based on the test results, the WQ data for 2006 and 2010 were excluded from the analysis for all environmental variables, while the values of nitrite nitrogen were excluded for 2017 and 2018.

Variables which showed a significant difference between the sampling site pairs were oxygen saturation (SS1/SS2, SS1/SS3, SS2/SS3), nitrite nitrogen (SS1/SS2, SS1/SS3), total nitrogen (SS1/SS2), and orthophosphates (SS1/SS3, SS2/SS3). Decrease of the mean oxygen saturation was observed going downstream from the first sampling site (Figure 4), while the opposite trend was observed for nitrite nitrogen and orthophosphates (Figures 5 and 6). Total nitrogen showed the highest mean value at the sampling site dominated by urban areas (SS2, Figure 7).

Retention effect of the forested riparian buffer (SS1) calculated against urban areas was 6.73% for total nitrogen and 14.38% for nitrite nitrogen. On the other hand, retention effects of the forested riparian buffer (SS1) against the agricultural land use (SS3) were 17.66% and 16.64% for nitrite nitrogen and orthophosphates, respectively.

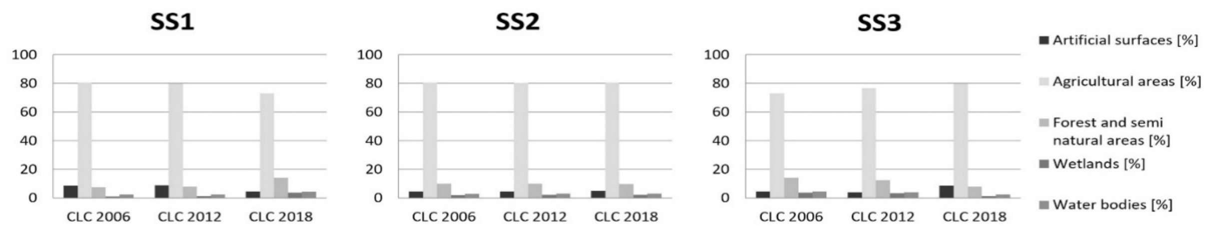

Figure 2. Percentage of land cover types in 2006, 2012, and 2018 within the 20 km radius from the sampling sites.

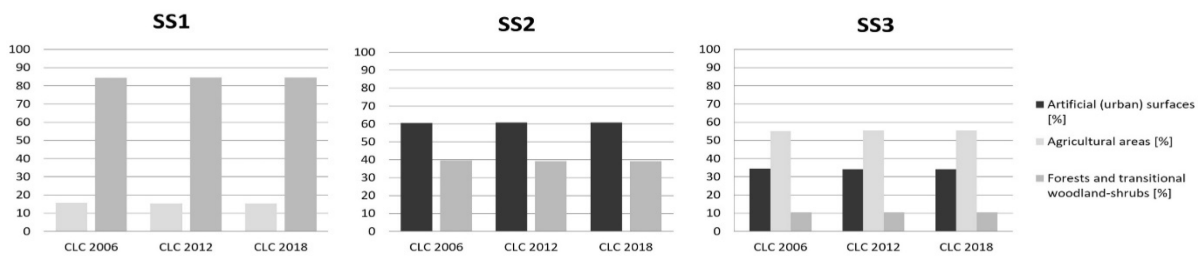

Figure 3. Percentage of land cover types in 2006, 2012 and 2018 within the 500m radius from sampling sites.

Table 3. Descriptive statistics for water quality variables at the sampling sites.

Environmental variable	Sampling site	Retention Effect of SS1 riparian buffer (%)	Mean	Standard Deviation	Number of samples	p
Saturation	SS1	-	89.928	9.064		
	SS2		86.086	12.515	139	0.001
	SS1	-	89.971	9.040		
	SS3		82.376	25.265	139	0.001
	SS2	-	86.752	10.508		
	SS3		82.272	25.434	137	0.038
Total nitrogen	SS1	6.73	1.472	0.605		
	SS2		1.578	0.568	112	0.025
Nitrite nitrogen	SS1	17.66	0.018	0.006		
	SS3		0.021	0.008	116	<0.001 §
	SS1	14.38	0.018	0.006		
	SS2		0.020	0.008	117	0.002 §
Orthophosphates	SS1	16.64	0.044	0.021		
	SS3		0.053	0.018	138	<0.001 §
	SS2	-	0.049	0.019		
	SS3		0.053	0.018	137	<0.001 §

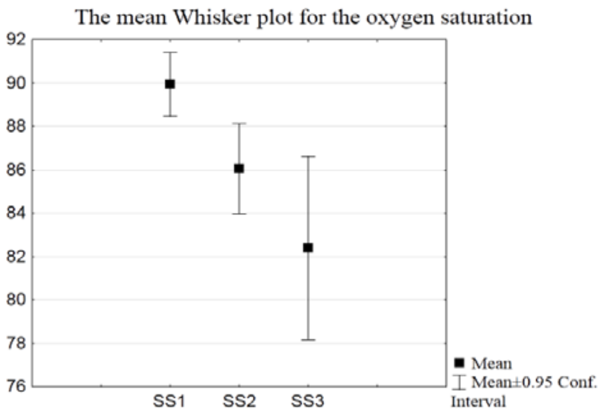

Figure 4. The range and mean values of oxygen saturation at the sampling sites.

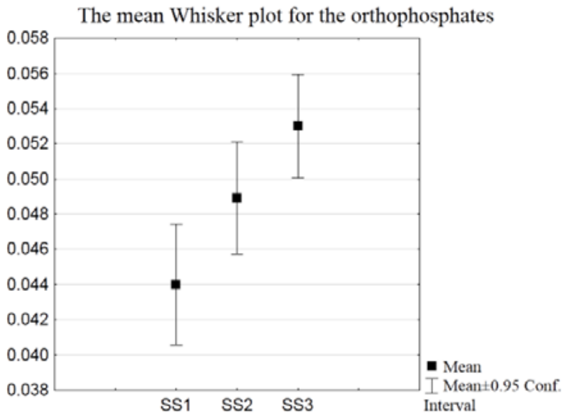

Figure 6. The range and mean values of orthophosphates at the sampling sites.

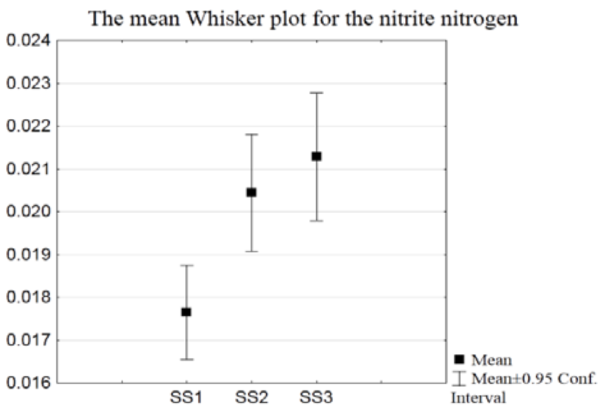

Figure 5. The range and mean values of nitrite nitrogen at the sampling sites.

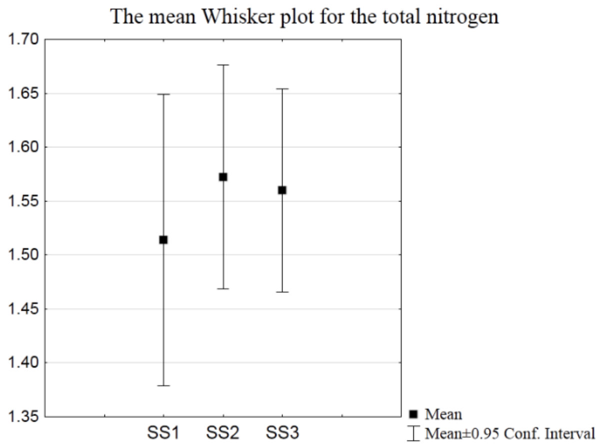

Figure 7. The range and mean values of the total nitrogen at the sampling sites.

4. DISCUSSION

4.1. Land use patterns

The research design applied in our study allowed reliable comparison of impacts which agricultural, urban, and forest land use types have on the Tisza River water quality at the local (buffer) scale. These influences were estimated using the existing long-term monitoring data. Instead of correlating land use with water quality data collected over a relatively narrow timeframe, along widely distributed rivers of a single watershed, the opposite approach was applied in our study. Monthly water quality values were compared between the three long-term monitoring stations along the Tisza River, having contrasting but consistent land use patterns at a local riparian scale (SS1 - forests and transitional woodland shrubs ~84%; SS2 - artificial (urban) surfaces ~60%/; SS3 - agricultural areas ~55%). The proportions of urban and agricultural land use at SS2 and SS3 (within the 500 m radius from sampling sites) were above the threshold values which were previously shown to significantly influence water quality (Tromboni & Dodds, 2017; Li et al., 2021). According to Tromboni & Dodds (2017), when relatively small proportions (20-40%) of watershed or riparian zone are converted to urban areas, nutrient concentrations (total nitrogen and total phosphorus) may rapidly increase. Tromboni & Dodds (2017) have ascribed this significant increase in nutrients to the direct exposure of riverbank to urban areas, which was also confirmed in our study. Furthermore, the equivalent threshold for agricultural areas, which may markedly increase the nutrient content was previously reported to be in the range of 50-60% (Monteagudo et al., 2012; Li et al., 2021).

4.2. Water quality parameters

Our results confirmed the positive effect that natural forested and shrub areas within the local riparian scale have on river oxygen and nutrient regimes. Forests and natural land use types are considered as factors which may improve the trophic status of a river and factors influencing it (Ding et al., 2015; de Oliveira et al., 2016; Balazovicova & Skodova, 2022). Also, our study demonstrated significant increase in nutrients at field sites dominated by urban or agricultural land. Negative influence of urban and agricultural riparian areas on river water quality has been well documented previously (Ding et al., 2015; de Oliveira et al., 2016; Gu et al., 2019). Rivers and streams with forested riparian buffers generally have a better water quality and better oxygen regime, compared to the ones with artificial land use (Wasson et al., 2010). A significant decrease of oxygen saturation was observed in our study, going downstream from the sampling site with natural areas (SS1), over the site dominated by urban areas (SS2), to the site surrounded by arable land (SS3). These results are in line with previous studies. According to de Oliveira et al., (2016), urban land use can be seen as a great oxygen consumer, as was the case in the Velhas River. Moreover, Ngoye & Machiwa (2004) have demonstrated that sites found within forested catchments have a higher level of dissolved oxygen and lower nitrogen levels, compared to those surrounded by farmlands, industrial and residential areas in the tropical Ruvu River watershed.

We observed a significant difference in the total nitrogen between the forest/shrub sites and the site dominated by urban surfaces. Similarly, a positive correlation of urban land use and the total nitrogen content in rivers was also found in previous studies (Sun et al., 2013; Tromboni & Dodds, 2017; Song et al., 2020). In case of the Haihe River basin, anthropogenic land use components, such as residential areas and road density showed a significant influence on water nitrogen concentration compared to the surrounding agricultural areas (Sun et al., 2013). Song et al., (2020) also found that the total nitrogen was best predicted at the local scale (up to a 200 m radius of the riparian buffer zone) by urban greenspace areas, while showing a negative correlation with forest surfaces in rapidly urbanized areas. Such negative relationships between the percentage of forest cover and the total and nitrate nitrogen were previously mostly attributed to the filtering effect of the forest land (Wang et al., 2013; Prosser et al., 2020). In line with this, our results show that the nitrite nitrogen content was significantly higher at both sites (SS2 and SS3) with the dominance of artificial land use types, compared to the one with natural areas (SS1). Nitrite nitrogen is formed when oxygen is limited, and its high levels, together with high ammonia levels, imply pollution with sewage effluents (Brandt et al., 2017). The mean and range nitrite values at all three sampling sites in our study were above the threshold. Although ammonia level wasn't analyzed in our study, according to Leščešen et al., (2018), for the period 2004-2013, the highest level of this nutrient was reported in the Tisza River, compared to other Middle Danube tributaries. Vrzel et al., (2016) have also found that in the neighboring Sava River watershed, the fecal contamination and urban wastewater were the primary sources of nitrates in water.

When agricultural land is the dominant land cover class in a river watershed (Coulter et al., 2004; Lawniczak et al., 2016), or in the riparian zone

(Mwaijengo et al., 2020), the orthophosphates content tends to increase. In our study, significantly higher orthophosphates content was found at the site dominated with arable land (SS3), compared to the sites with natural forests and urban areas. The loss of phosphorus via bank erosion is considered the dominant source of this nutrient in rivers (Kronvang et al., 2005). According to Kovacs et al., (2009), flood waves on the Tisza River may bring in a significant amount of phosphorus originating from river shoreline erosion and flooding. Together with floods, water erosion is the most common natural disaster in the area studied, and the riparian buffers are suggested as a potential management measure (Jakovljević et al., 2021).

4.3. Retention effect of the natural riparian buffer

Although riparian buffers of similar characteristics as those in our study may retain most of the total nitrogen from the surrounding agricultural land (Feld et al., 2018; Aguiar et al., 2015), we observed a relatively low retention potential of the forest buffer for both the total nitrogen and nitrite nitrogen. The calculated retention potential for orthophosphates was also relatively low, compared to other studies (Aguiar et al., 2015; Feld et al., 2018). On the other hand, in a review study which summarized effectiveness of vegetated buffers, the retention capacity for nutrients ranged between 12 and 100% (Prosser et al., 2020). Retention of the total phosphorus in riparian buffers is mainly controlled by sedimentation of particulate phosphorus, while the efficiency of this process mainly depends on the riparian buffer width (Hoffmann et al., 2009). Sufficient width of the buffer composed of woody soils, capable of eliminating nutrients in an agricultural area was shown to be 60 m (Aguiar et al., 2015). Meanwhile, Kronvang et al. (2005) suggested that buffers should be at least 90 m wide in order to capture 90% of the soil material delivered from erosion rills from the adjoining agricultural fields. Since the buffer width examined in our study exceeded the described criteria, this implies that the potential use of buffer strips along the Tisza River is rather limited and should be integrated within a wider management framework (Cole et al., 2020). Moreover, in addition to the buffer width and plant community composition, the slope and the general maintenance of the riparian zone should be considered as well (Prosser et al., 2020; Raduca et al., 2021). On the other hand, as reported in previous studies, a buffer strip saturated with nutrients can also act as a source of pollutants, rather than a sink (Cole et al., 2020), which might be the case in the study area.

One of the most frequently reported limitations in the research design of buffer strips is the poor quantification of net buffer effects (Feld et al., 2018). One of the best ways for achieving this is by comparing environmental conditions before and after the buffer construction against control sites (Feld et al., 2018). In contrast, the design applied in our study allowed for a rough, but low-cost, long-term estimate of potential buffer effectiveness in the pre-restoration phase. Furthermore, water quality data in our study were obtained from long-term monitoring stations along the Tisza River, not requiring extra expenditures normally required for field sampling.

5. CONCLUSION

This study demonstrated the net retention effect of naturally formed/remnant buffer strips along a lowland, temperate, non-wadeable river, in a predominantly agricultural landscape, over a 11-14 years period. Unlike agricultural and urban areas, natural and seminatural forests and shrubs had a favorable long-term influence on nutrient concentrations and oxygen regime of the Tisza River. Although previous studies reported a significant retention effect of orthophosphates and nitrite/nitrate content, its effectiveness here was relatively low, despite a similar scale of the explored forested buffer. This implies a limited performances of riparian buffers as a main or only management option in the Pannonian landscape, the agricultural hotspot of Central and Eastern Europe (Nagy et al., 2018).

However, the buffer assessment design applied in this study may be successfully used in pre-restoration monitoring, prior to the construction of buffer strips, as a surrogate to post-restoration assessment. Rough estimation of the buffer characteristics and effectiveness can be made before the construction works.

In the same time, the buffer zones are considered as nature-based solutions for extreme flood events in the area studied (Jakovljević et al., 2021), as well as the measures for mitigating climate change in the Carpathian catchment (Szalińska et al., 2020). Therefore, findings of our study may assist the future restoration actions along the Tisza and similar rivers in the Pannonian plain.

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REFERENCES

Aguiar Jr, T. R., Rasera, K., Parron, L. M., Brito, A. G., & Ferreira, M. T., 2015. *Nutrient removal effectiveness by riparian buffer zones in rural temperate watersheds: the impact of no-till crops practices*. Agricultural Water Management, 149, 74-80. https://doi.org/10.1016/j.agwat.2014.10.031

Balazovicova, L., & Skodova, M., 2022. *Vegetation and land use analysis for runoff estimation in small forested catchment: A case study of Tajovsky Brook in Slovakia.* Carpathian Journal of Earth and Environmental Sciences, 17(1), 81-92.

Barbosa, A. S., Pires, M. M., & Schulz, U. H., 2020. *Influence of land-use classes on the functional structure of fish communities in Southern Brazilian headwater streams*. Environmental management, 65(5), 618-629. https://doi.org/10.1007/s00267-020-01274-9

Brandt, M. J., Johnson, K. M., Elphinston, A. J., & Ratnayaka, D. D., 2017. *Chemistry, Microbiology and Biology of Water*. In M. J. Brandt, K. M. Johnson, A. J. Elphinston, & D. D. Ratnayaka (Eds.), Twort's water supply (7th ed., pp. 235-321). Butterworth-Heinemann.

Brumberg, H., Beirne, C., Broadbent, E. N., Almeyda Zambrano, A. M., Almeyda Zambrano, S. L., Quispe Gil, C. A., Lopez Gutierrez, B., Eplee, R., & Whitworth, A., 2021. *Riparian buffer length is more influential than width on river water quality: A case study in southern Costa Rica*. Journal of Environmental Management, 286, 112132. http://dx.doi.org/10.1016/j.jenvman.2021.112132

CLC, 2006. *Corine Land Cover, v.2020_20u1*. European Union, Copernicus Land Monitoring Service 2006, European Environment Agency (EEA) https://land.copernicus.eu/pan-european/corine-land-cover/clc-2006?tab=download (accessed 12 December 2020)

CLC, 2012. *Corine Land Cover, version v.2020_20u1*. European Union, Copernicus Land Monitoring Service 2012, European Environment Agency (EEA) https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012?tab=download (accessed 12 December 2020)

CLC, 2018. *Corine Land Cover, version v.2020_20u1*. European Union, Copernicus Land Monitoring Service 2018, European Environment Agency (EEA) https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download (accessed 12 December 2020)

Cole, L. J., Stockan, J., & Helliwell, R., 2020. *Managing riparian buffer strips to optimise ecosystem services: A review*. Agriculture, Ecosystems & Environment, 296, 106891. https://doi.org/10.1016/j.agee.2020.106891

Coulter, C. B., Kolka, R. K., & Thompson, J. A., 2004. *Water quality in agricultural, urban, and mixed land use watersheds 1*. JAWRA Journal of the American Water Resources Association, 40(6), 1593-1601. https://doi.org/10.1111/j.1752-1688.2004.tb01608.x

de Oliveira, L. M., Maillard, P., & de Andrade Pinto, É. J., 2016. *Modeling the effect of land use/land cover on nitrogen, phosphorous and dissolved oxygen loads in the Velhas River using the concept of exclusive contribution area*. Environmental monitoring and assessment, 188(6), 333. https://doi.org/10.1007/s10661-016-5323-2

Ding, J., Jiang, Y., Fu, L., Liu, Q., Peng, Q., & Kang, M., 2015. *Impacts of land use on surface water quality in a subtropical River Basin: a case study of the Dongjiang River Basin, Southeastern China*. Water, 7(8), 4427-4445. https://doi.org/10.3390/w7084427

Dodds, W. K., Bouska, W. W., Eitzmann, J. L., Pilger, T. J., Pitts, K. L., Riley, A. J., ... Thornbrugh, D. J., 2009. *Eutrophication of US freshwaters: analysis of potential economic damages*. Environmental Science and Technology, 43(1), 12-19. https://doi.org/10.1021/es801217q

Feld, C. K., Birk, S., Bradley, D. C., Hering, D., Kail, J., Marzin, A., ...& Friberg, N., 2011. *From natural to degraded rivers and back again: a test of restoration ecology theory and practice*. Advances in ecological research, 44, 119-209. https://doi.org/10.1016/B978-0-12-374794-5.00003-1

Feld, C. K., Fernandes, M. R., Ferreira, M. T., Hering, D., Ormerod, S. J., Venohr, M., & Gutiérrez-Cánovas, C., 2018. *Evaluating riparian solutions to multiple stressor problems in river ecosystems—a conceptual study*. Water research, 139, 381-394. https://doi.org/10.1016/j.watres.2018.04.014

Grudzinski, B., Fritz, K., & Dodds, W., 2020. *Does Riparian Fencing Protect Stream Water Quality in Cattle-Grazed Lands?*. Environmental management, 66(1), 121-135. https://doi.org/10.1007/s00267-020-01297-2

Gu, Q., Hu, H., Ma, L., Sheng, L., Yang, S., Zhang, X., ...& Chen, L., 2019. *Characterizing the spatial variations of the relationship between land use and surface water quality using self-organizing map approach*. Ecological Indicators, 102, 633-643. https://doi.org/10.1016/j.ecolind.2019.03.017

Haag, D., & Kaupenjohann, M., 2001. *Landscape fate of nitrate fluxes and emissions in Central Europe: a critical review of concepts, data, and models for transport and retention*. Agriculture, ecosystems & environment, 86(1), 1-21.

Hoffmann, C. C., Kjaergaard, C., Uusi-Kämppä, J., Hansen, H. C. B., & Kronvang, B., 2009. *Phosphorus retention in riparian buffers: review of their efficiency*. Journal of Environmental Quality, 38(5), 1942-1955. https://doi.org/10.2134/jeq2008.0087

ICPDR – International Commission for the Protection of the Danube River -ICPDR, 2008. *Analysis of the Tisza River Basin 2007. Initial step toward the Tisza River Basin Management Plan – 2009*. https://www.icpdr.org/main/sites/default/files/Tisza_RB_Analysis_2007.pdf

Jakovljević, D., Pešić, A. M., & Joksimović, D. M., 2021.

Protection from harmful effects of water—examples from Serbia. In P. Samui, H. Bonakdari, & R. Deo (Eds.), Water Engineering Modeling and Mathematic Tools (pp. 157-175). https://doi.org/10.1016/B978-0-12-820644-7.00026-8

Kellner, E., Hubbart, J., Stephan, K., Morrissey, E., Freedman, Z., Kutta, E., & Kelly, C., 2018. *Characterization of sub-watershed-scale stream chemistry regimes in an Appalachian mixed-land-use watershed*. Environmental monitoring and assessment, 190(10), 1-18. https://doi.org/10.1007/s10661-018-6968-9

Kovacs, A., Kozma, Z., Istvánovics, V., & Honti, M., 2009. *Phosphorus retention patterns along the Tisza River, Hungary*. Water Science and Technology, 59(2), 391-397. https://doi.org/10.2166/wst.2009.888

Kronvang, B., Bechmann, M., Lundekvam, H., Behrendt, H., Rubaek, G. H., Schoumans, O. F., ...& Hoffmann, C. C., 2005. *Phosphorus losses from agricultural areas in river basins: Effects and uncertainties of targeted mitigation measures*. Journal of environmental quality, 34(6), 2129-2144. https://doi.org/10.2134/jeq2004.0439

Lawniczak, A. E., Zbierska, J., Nowak, B., Achtenberg, K., Grześkowiak, A., & Kanas, K., 2016. *Impact of agriculture and land use on nitrate contamination in groundwater and running waters in central-west Poland*. Environmental monitoring and assessment, 188(3), 172. https://doi.org/10.1007/s10661-016-5167-9

Le Moal, M., Gascuel-Odoux, C., Ménesguen, A., Souchon, Y., Étrillard, C., Levain, A., …& Pinay, G., 2019. *Eutrophication: a new wine in an old bottle*?. Science of the Total Environment, 651, 1-11. https://doi.org/10.1016/j.scitotenv.2018.09.139

Leščešen, I., Dolinaj, D., Pantelić, M., Savić, S., & Milošević, D., 2018. *Statistical Analysis of Water Quality Parameters in Seven Major Serbian Rivers during 2004–2013 Period*. Water Resources, 45(3), 418-426. https://doi.org/10.1134/S0097807818030089

Li, Y., Boswell, E., & Thompson, A., 2021. *Correlations between land use and stream nitrate-nitrite concentrations in the Yahara River Watershed in south-central Wisconsin*. Journal of Environmental Management, 278, 111535. https://doi.org/10.1016/j.jenvman.2020.111535

Liang, K., Jiang, Y., Qi, J., Fuller, K., Nyiraneza, J., & Meng, F. R., 2020. *Characterizing the impacts of land use on nitrate load and water yield in an agricultural watershed in Atlantic Canada*. Science of the Total Environment, 729, 138793. https://doi.org/10.1016/j.scitotenv.2020.138793

Miletić, A., Radomirović, M., Đorđević, A., Bogosavljević, J., Lučić, M., & Onjia, A., 2022. *Geospatial mapping of ecological risk from potentially toxic elements in soil in the Pannonian-Carpathian border area south of the Danube.* Carpathian Journal of Earth and Environmental Sciences, 17(2), 351-363. http://10.26471/cjees/2021/016/160

Monteagudo, L., Moreno, J. L., & Picazo, F., 2012. *River eutrophication: irrigated vs. non-irrigated agriculture through different spatial scales*. Water Research, 46(8), 2759-2771. https://doi.org/10.1016/j.watres.2012.02.035

Mwaijengo, G. N., Msigwa, A., Njau, K. N., Brendonck, L., & Vanschoenwinkel, B., 2020. *Where does land use matter most? Contrasting land use effects on river quality at different spatial scales*. Science of the Total Environment, 715, 134825. https://doi.org/10.1016/j.scitotenv.2019.134825

Nagy, A., Fehér, J., & Tamás, J., 2018. *Wheat and maize yield forecasting for the Tisza River catchment using MODIS NDVI time series and reported crop statistics*. Computers and Electronics in Agriculture, 151, 41-49. https://doi.org/10.1016/j.compag.2018.05.035

Nava-López, M. Z., Diemont, S. A., Hall, M., & Ávila-Akerberg, V., 2016. *Riparian buffer zone and whole watershed influences on river water Quality: implications for ecosystem services near megacities*. Environmental Processes, 3(2), 277-305. http://dx.doi.org/10.1007%2Fs40710-016-0145-3

Ngoye, E., & Machiwa, J. F., 2004. *The influence of land-use patterns in the Ruvu river watershed on water quality in the river system*. Physics and Chemistry of the Earth, Parts A/B/C, 29(15-18), 1161-1166. http://dx.doi.org/10.1016%2Fj.pce.2004.09.002

Pavić, D., 2006 *Potamološke karakteristike Tise u Srbiji i predispozicije za razvoj nautičkog turizma* [*Potamological characteristics of the Tisa River in Serbia and predispositions for nautical tourism development*] (Doctoral Dissertation). University of Novi Sad, Novi Sad. Retrieved from https://www.cris.uns.ac.rs/searchDissertations.jsf

Pavić, D., Dolinaj, D., Dragićević, S., 2009. *Thermal regime of water and ice on the Tisza River in Serbia*. Zbornik radova-Geografski fakultet Univerziteta u Beogradu, 57, 35-46.

Prosser, R. S., Hoekstra, P. F., Gene, S., Truman, C., White, M., & Hanson, M. L., 2020. *A review of the effectiveness of vegetated buffers to mitigate pesticide and nutrient transport into surface waters from agricultural areas*. Journal of environmental management, 261, 110210. https://doi.org/10.1016/j.jenvman.2020.110210

Raduca, C., Boengiu, S., Mititelu-Ionus, O., & Enache, C., 2021. *Correlation of the relief conditions, hydrographic network features and human interventions within the Blahnita river basin (Southwestern Romania)*. Carpathian Journal of Earth and Environmental Sciences, 16(1), 117-127. Doi:10.26471/cjees/2021/016/160

Read, E. K., Carr, L., De Cicco, L., Dugan, H. A., Hanson, P. C., Hart, J. A., ... & Winslow, L. A., 2017. *Water quality data for national-scale aquatic research: The Water Quality Portal*. Water Resources Research, 53(2), 1735-1745. https://doi.org/10.1002/2016WR019993

Shi, P., Zhang, Y., Li, Z., Li, P., & Xu, G., 2017. *Influence of land use and land cover patterns on seasonal water quality at multi-spatial scales*. Catena, 151, 182-190. https://doi.org/10.1016/j.catena.2016.12.017

Song, Y., Song, X., Shao, G., & Hu, T., 2020. *Effects of land use on stream water quality in the rapidly urbanized areas: A multiscale analysis*. Water, 12(4), 1123. https://doi.org/10.3390/w12041123

StatSoft, 2021. *Statistica v. 14.0*. Ultimate Academic Bundle (ftp://ftp.statsoft.de).

Su, Z. H., Lin, C., Ma, R. H., Luo, J. H., & Liang, Q. O., 2015. *Effect of land use change on lake water quality in different buffer zones*. Applied Ecology and Environmental Research, 13(3), 639-653.

Sun, R., Chen, L., Chen, W., & Ji, Y., 2013. *Effect of land-use patterns on total nitrogen concentration in the upstream regions of the Haihe River Basin, China*. Environmental management, 51(1), 45-58. https://doi.org/10.1007/s00267-011-9764-7

Szalińska, E., Orlińska-Woźniak, P., & Wilk, P., 2020. *Sediment load variability in response to climate and land use changes in a Carpathian catchment (Raba River, Poland)*. Journal of Soils & Sediments: Protection, Risk Assessment, & Remediation, 20(6). https://doi.org/10.1007/s11368-020-02600-8

Tiwari, T., Lundström, J., Kuglerová, L., Laudon, H., Öhman, K., & Ågren, A. M., 2016. *Cost of riparian buffer zones: A comparison of hydrologically adapted site-specific riparian buffers with traditional fixed widths*. Water Resources Research, 52(2), 1056-1069. https://doi.org/10.1002/2015WR018014

Tromboni, F., & Dodds, W. K., 2017. *Relationships between land use and stream nutrient concentrations in a highly urbanized tropical region of Brazil: thresholds and riparian zones*. Environmental management, 60(1), 30-40. https://doi.org/10.1007/s00267-017-0858-8

Underwood, A. J. 1991. *Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations in natural populations*. Marine and Freshwater Research, 42(5), 569-587. https://doi.org/10.1016/0022-0981(92)90094-Q

Valkama, E., Usva, K., Saarinen, M., & Uusi-Kämppä, J., **2019**. *A meta-analysis on nitrogen retention by buffer zones*. Journal of environmental quality, 48(2), 270-279. https://doi.org/10.2134/jeq2018.03.0120

Vári, A., Podschun, S. A., Erős, T., Hein, T., Pataki, B., Iojă, I. C., ... & Báldi, A., 2022. *Freshwater systems and ecosystem services: Challenges and chances for cross-fertilization of disciplines.* Ambio, 51(1), 135-151. https://doi.org/10.1007/s13280-021-01556-4

Vrebos, D., Beauchard, O., & Meire, P., 2017. *The impact of land use and spatial mediated processes on the water quality in a river system*. Science of the Total Environment, 601, 365-373. https://doi.org/10.1016/j.scitotenv.2017.05.217

Vrzel, J., Vuković-Gačić, B., Kolarević, S., Gačić, Z., Kračun-Kolarević, M., Kostić, J., & Ogrinc, N., 2016. *Determination of the sources of nitrate and the microbiological sources of pollution in the Sava River Basin*. Science of the Total Environment, 573, 1460-1471. http://dx.doi.org/10.1016/j.scitotenv.2016.07.213

Wang, M., Duan, L., Wang, J., Peng, J., & Zheng, B., 2020. *Determining the width of lake riparian buffer zones for improving water quality base on adjustment of land use structure*. Ecological Engineering, 158, 106001. https://doi.org/10.1016/j.ecoleng.2020.106001

Wang, R., Xu, T., Yu, L., Zhu, J., & Li, X., 2013. *Effects of land use types on surface water quality across an anthropogenic disturbance gradient in the upper reach of the Hun River, Northeast China*. Environmental monitoring and assessment, 185(5), 4141-4151. https://doi.org/10.1007/s10661-012-2856-x

Wasson JG, Villeneuve, B., Iital, A., Murray-Bligh, J. O. H. N., Dobiasova, M., Bacikova, S., Chandesris, A., 2010. *Large-scale relationships between basin and riparian land cover and the ecological status of European rivers*. Freshwater Biology, 55(7), 1465-1482. https://doi.org/10.1111/j.1365-2427.2010.02443.x

Xu, J., Jin, G., Tang, H., Mo, Y., Wang, Y. G., & Li, L., 2019. *Response of water quality to land use and sewage outfalls in different seasons*. Science of The Total Environment, 696, 134014. https://doi.org/10.1016/j.scitotenv.2019.134014

Yadav, S., Babel, M. S., Shrestha, S., & Deb, P., 2019. *Land use impact on the water quality of large tropical river: Mun River Basin, Thailand*. Environmental monitoring and assessment, 191(10), 1-22. https://doi.org/10.1007/s10661-019-7779-3

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